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ALUMINUM MATRIX COMPOSITES AND THEIR SUPERPLASTICITY

Tang Cairong Li Senquan Li Hualun /9*

ABSTRACT

This paper introduces in simple terms manufacturing methods associated with aluminum matrix composite materials, superplasticity research as well as its applications, and probes structural faults during the manufacturing of aluminum matrix composite materials. In conjunction with this, it brings together a crossing of subjects to expound on trends in the development of research on aluminum matrix composite material superplasticity and its applications.

I. INTRODUCTION

Metallic matrix composite material is the focus and hot topic of research in the realm of composite materials in the world today. It is also one of the high technologies which is in the process of exploration and development. Compared to ordinary metal materials, it has the advantages of light weight, relative strength, and relatively high moduli. It possesses relatively high shear moduli and rigidities, good high temperature and low temperature characteristics, and thermal stability, as well as very strong resistance to corrosion. Working can be carried out with such methods as electrical resistance welding, diffusion linkages, as well as rod welding, and so on. When option is made for the use of noncontinuous strengthening materials to act as strengthening bodies, it is possible to use conventional pressure working equipment for manufacture and secondary working.

Aluminum alloys--no matter whether it is on military aircraft or civilian aircraft--take first place for the amount used in all cases. Among these, on civilian aircraft, the amount used reaches as high as approximately 80%.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

Aluminum matrix composite materials are, among metallic matrix composite materials, the ones which get the most research and the most applications. They are also one of the materials with the best plasticity. Plastic errors have already become one of the key obstacles to taking metallic matrix composite materials and applying them to engineering (Table 1).

TABLE 1. SiC_p / Al COMPOSITE MATERIAL CLASSICAL MECHANICS PROPERTIES

1 基体合金+SiC_p,%		2 弹性模量,GPa	3 屈服强度,MPa	4 极限强度,MPa	5 延伸率,%
6061+SiC_p	15	97	400	450	7.5
	40	145	448	586	2.0
2124+SiC_p	25	114	414	565	5.6
	40	152	517	689	1.1
7090+SiC_p	20	103	655	724	2.5
	40	145	689	760	0.9
7091+SiC_p	15	97	579	689	1.2
	40	139	620	655	1.1

Key: (1) Substrate Alloy (2) Elasticity Modulus (3) Yielding Strength (4) Limit Strength (5) Percentage Elongation

Metal superplasticity techniques are a borderline, comprehensive subject the development of which rises on the foundation of such branches of learning as metallic physics, metallic materials science, metallic deformation mechanics, and plastic working theory. As far as the discovery of metallic superplasticity is concerned, research already has a history associated with the last 60 years. In it, aluminum alloy superplasticity research and applications mature with each passing day. With regard to the development of superplasticity in metallic matrix composite materials, in conjunction, aluminum matrix composite material research results are taken and combined with superplastic forming techniques. This is to determine effective means with good prospects for the difficult forming problems. The aim of this article is--on the foundation of reviewing aluminum matrix composite material manufacturing methods as well as superplasticity research--to probe directions in the development of research on this type of composite material superplasticity.

II. MANUFACTURING METHODS

1. Powder Metallurgy Methods

The key processes in using powder metallurgy methods to /10 manufacture aluminum matrix composite materials are: constituent mixing, cold pressing, hot pressing, push out composite material from the mould. The microscopic analysis results of Divecha and others clearly show that the interior organization of this type of composite material is not uniform. There clearly exist areas rich in strengthening bodies and areas poor in them thus lowering the plasticity of the composite material. In order to improve wetting characteristics between strengthening bodies and substrate as well as forming capabilities, it is necessary--before constituent mixing--to take strengthening bodies and carry out surface treatment. Moreover, it is possible to make strengthening body distribution tend toward uniformity.

2. Die Casting Methods

First of all, take strengthening bodies and make them into prefabricated pieces. Following that, take the mixture, melt it, and pour it into the mould. Under pressure, crystallization will make composite material.

When making prefabricated pieces, it is possible to use inorganic glues to act as adhesives. Without using inorganic glues, it is also possible to make good prefabricated pieces and aluminum matrix composite materials.

3. Liquid Metal Permeation Methods

This method takes extrusion casting as its foundation. The technical process is to first take strengthening bodies and make them into prefabricated pieces, placing them into pressure molds. Then, make liquid metal, under pressure, seep into the prefabricated pieces.

It is possible to opt for the use of such methods as vacuum extraction types or pressure subsidence to manufacture prefabricated pieces. The clearance rate associated with prefabricated pieces was maintained at 95%~85%.

During extrusion, metallic fluid temperatures are generally above liquid phase linear temperatures at 150 ~ 250°C. Metallic fluid seep in speed is 10mm/s. The pressure applied is 50 ~ 100MPa. After liquid metal has seeped into prefabricated pieces, it is necessary to maintain pressure for an adequate period--right through to complete solidification.

4. Composite Casting Methods

Taking an aluminum alloy placed at two phase liquid-solid temperatures and applying agitation, it makes the aluminum alloy turn into a paste-like thick substance with high viscosity. At this time, strengthening body particles are thrown into the thick material. In conjunction with this, it causes a uniform spreading. Taking aluminum liquid and raising the temperature above the liquid phase line, it is then possible to pour ingots and parts.

5. Spray Sedimentation Methods

First of all, take components and mix them. Following that, take liquid droplet metal flow associated with gas atomization and spray it directly onto cold metal substrate, causing metal droplets to solidify, producing a sedimentation layer with an approximate thickness of several centimeters and more or less closely knit. Spraying continuously, it is possible to obtain ingots or products of required dimensions. When sedimentation layers turn relatively thick, one should then use the aid of gas and sedimentation layer surface radiation cooling to carry out rapid solidification.

III. ALUMINUM MATRIX COMPOSITE MATERIAL SUPERPLASTICITY AND APPLICATIONS

Superplastic forming techniques are capable of resolving difficult problems associated with materials which are difficult to form taking complicated shapes. Plastic working technology has very good prospects in such realms as aviation, space flight, and military industry, going a step further in the lightening of structural component weights and increasing the strength of total structures. Some results gotten domestically and abroad in the research areas of aluminum matrix composite material plasticity and applications are seen in Table 2.

TABLE 2. ALUMINUM MATRIX COMPOSITE MATERIAL SUPERPLASTICITY RESEARCH RESULTS

1 组 成	2 温度,℃	3 应变速率,s^{-1}	m 值 4	5 延伸率,%	6 处理方法
$10\%SiC_w/7475$	520	2×10^{-4}	0.8	350	
$10\%SiC_p/7064$	500～516	$1\times10^{-3}\sim10^{-2}$	>0.5	450	
$20\%SiC_w/2124$	520	3.3×10^{-1}	0.5	300	
PM-SiC_p/LY12 (SiC_p15%)	508	9.5×10^{-4}	0.74	220	热挤压 8
7 铸造 SiC_p12%LY12	510	1.1×10^{-4}		215	热挤压 8
7 铸造 SiC_p12%LY12	500～520	6.4×10^{-4}		293	均匀化+热压 9

10 注: w 表示晶须增强，p 表示颗粒增强，PM 表示粉末冶金法制造。

Key: (1) Constituents (2) Temperature (3) Strain Speed (4) Value (5) Percentage Elongation (6) Processing Method (7) Cast (8) Hot Extrusion (9) Homogenization + Hot Pressing (10) Note: w represents crystals needing strengthening, p represents particle strengthening, PM represents powder metallurgy manufacture.

Methods for aluminum matrix composite materials achieving superplasticity are primarily: (1) During original material manufacturing processes, superplastic structures are obtained. For example, powder metallurgy methods. Add in certain metallic elements. Use fine cast structure particles. Adjust manufacturing technical parameters during industrial processes, and so on. (2) Carrying out pretreatment methods on original materials. Among these are included solid solution--aging--rolling (or extrusion)--recrystallization; hot extrusion--rolling; homogenization--hot deformation; hot extrusion, and so on.

Aluminum matrix composite material superplasticity tensile test results clearly show: the appearance of a classical S form curve between flow stress and strain rate as shown in Fig.1; the influence of temperature on percentage elongation also has peak values as shown in Fig.2; demonstrate that strain speed sensitivity indices associated with superplastic flow characteristics--under certain strain speed conditions--exceed 0.5 as shown in Fig.3. The results above verify that aluminum matrix composite materials possess high strain speed sensitivities and their plasticity is at a relatively high level.

What is more important is that aluminum matrix composite materials, when at relatively high strain rates, still possess relatively high m values. This simply means that it is possible to use even higher rates in forming. This is extremely advantageous for actual superplastic formations and increasing production efficiency. When taking pretreated aluminum matrix composite materials through observations under a scanning electron microscope, it is discovered that the grain boundaries are medium and large angle grain boundaries conforming to the requirements of relatively high level or high level superplasticity.

After aluminum matrix composite materials go through superplastic stretching, when observed under an electron microscope, crystal particles wrapped around strengthening bodies produce rotation. In conjunction with this, they produce glide. At the same time, strengthening bodies also participate in this type of movement coordinating substrate crystal particles and manifesting clear superplastic flow characteristics. Aluminum matrix composite materials, during superplastic deformation processes, also manifest high density dislocation configurations, and there will be large numbers of holes existing as well, going deep into deformations and producing disadvantageous effects. /11

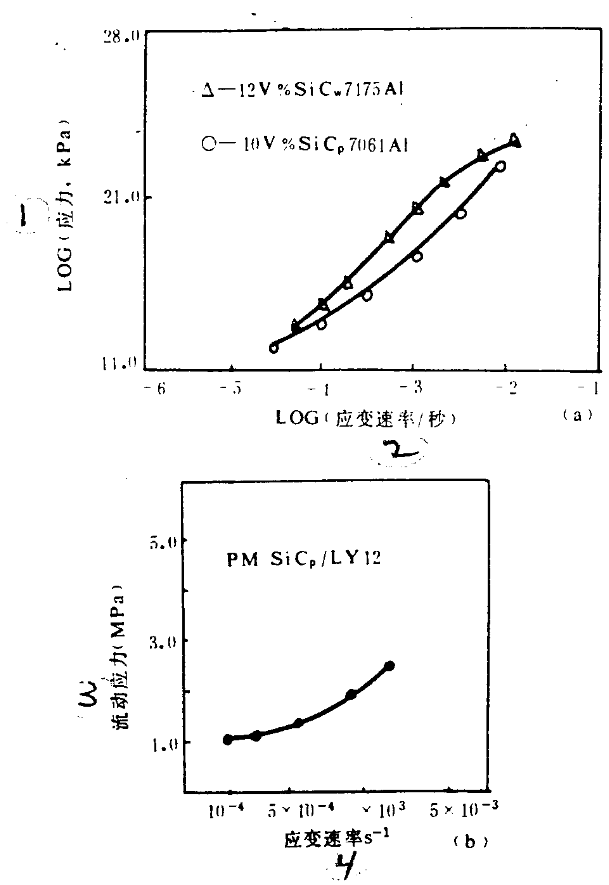

Fig.1 Influences of Strain Rate on Flow Stress

Key: (1) Stress (2) Strain Rate/Sec (3) Flow Stress (4) Strain Rate

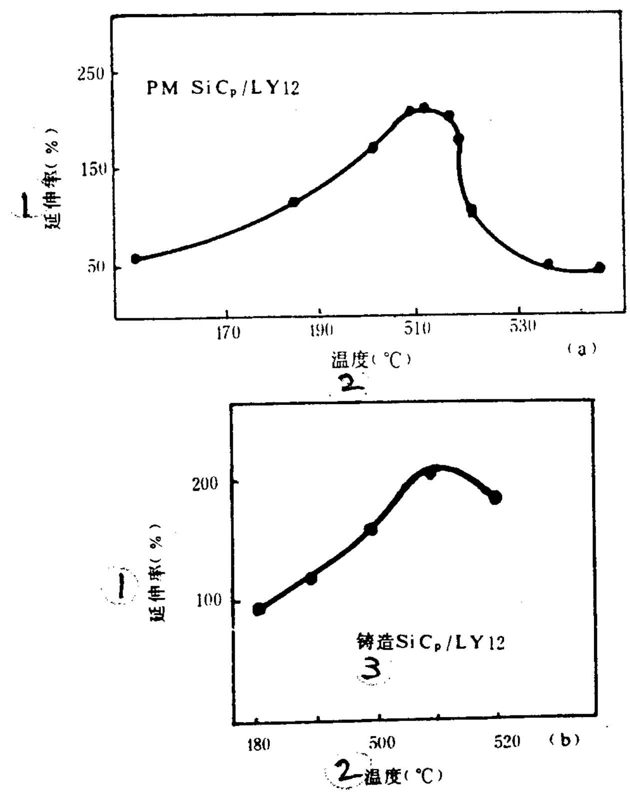

Fig.2 Influence of Deformation Temperature of Percentage Elongation

Key: (1) Percentage Elongation (2) Temperature (3) Cast

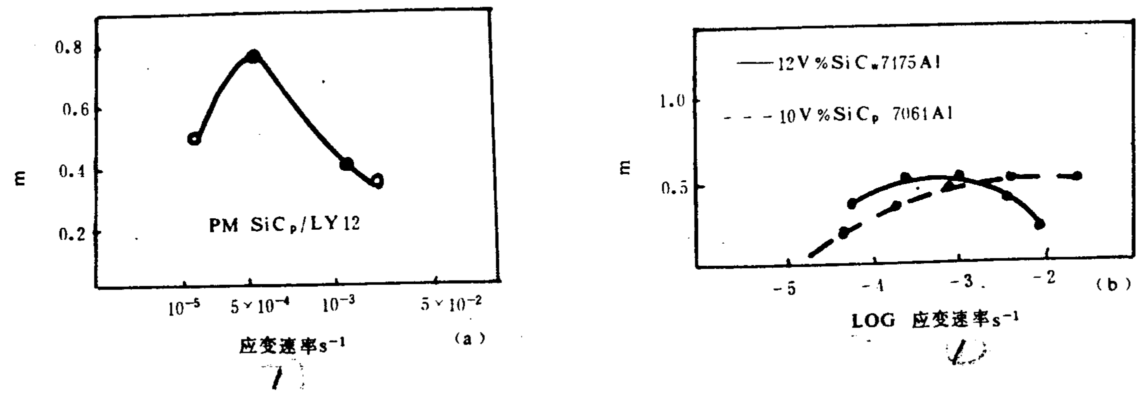

Fig.3 Strain Rate Sensitivity Index m Values

Key: (1) Strain Rate

Foreign superplastic applications of aluminum matrix composite materials include successfully forming such aviation parts as engine compartment doors, panels, sine wave purlins, and so on.

The special characteristics of using phase change superplacticity make it possible to carry out punch cut processing of small apertures (D/t<1) on micro components and to manufacture various types of mould form cavities associated with complicated shapes such as bakelite molds, plastic molds, die casting molds, hot forging molds, precision forging molds, cold extrusion molds, and so on. China has already also successfully manufactured die forged components. The maximum strain values reach as high as 165%.

IV. DISCUSSION

On the basis of production costs and the requirements of production in large lots, the use of casting methods to produce aluminum matrix composite materials has already basically been established. The use of spray sedimentation methods to obtain aluminum matrix composite materials is not only relatively simple, convenient, and easy for the realization of production in large lots as well as satisfying product requirements, but also, is capable of attaining relatively excellent overall mechanical properties as well as relatively good organizational structure. However, primary crystal particle dimensions are generally larger than 10 microns. Liquation is severe. The existence of such faults as air holes as well as not very uniform distributions of particles are basically difficult to overcome and eliminate. As a result, deformation through heat in order to facilitate the breaking up of coarse crystal particles, the welding shut of air holes, and uniform particle distribution are secondary working to prepare for applications having special industrial techniques which cannot be substituted for. However, opting for the use of universal deformation through heat expecting to obtain relatively excellent superplastic organizational structures is inadequate.

It is common knowledge that superplastic materials are generally material types susceptible to holes. Aluminum matrix composite materials are no exception either. During superplastic deformation processes, they easily show the appearance of holes.

In conjunction with this, on boundary surfaces associated with grain boundary slippage, production of holes is concentrated causing plasticity to drop. Because of this, the prevention of holes is extraordinarily necessary. In formation work processes, applying a certain numerical value of back pressure is capable of causing the number of holes to be reduced or contained. Introduction of strong exterior electric fields possesses the same results. At the same time, it is possible to increase the percentage elongation of material relatively greatly. Because of this, research on the influences of exterior formation conditions on aluminum matrix composite material superplasticity is an inevitable trend. The reason is that they are not only capable of improving material superplastic formation properties. They can be expected, moreover, to improve utilization properties after material formation.

Aluminum matrix composite material superplastic tensile test results have already gone through verification. Under relatively high strain rates, it still possesses good superplasticity. In depth research on superplastic deformation mechanisms associated with aluminum matrix composite materials, and, in conjunction with that, coordination of improvements in aluminum matrix composite material manufacturing methods practically demonstrate that aluminum matrix composite material superplastic formation under high strain rates is completely possible, thus causing aluminum matrix composite material superplastic research results to be easy to make practical applications and generalizations of.

On conventional metal pressure working equipment, the realization of aluminum matrix composite material superplastic working will produce obvious economic benefits and possesses broad prospects for application.

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